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MALAYSIAN ASSOCIATION OF RESEARCH SCIENTISTS

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This Certificate of Award is presented to

Dr. Tay Choo Chuan

For the invention/innovation of

**Simpler UNBab Mapping Function
For Global Positioning System (GPS)
Thopospheric Delay**

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PUBLICATIONS

Hamzah Sakidin , Mohd Rizam Abu Bakar, Mohd Rashid Md Shariff, Mohd Salmi Md Noorani, Abd. Nasir Matori, Azhari Mohamed. *Proceeding of 7th International Symposium & Exhibition On Geoinformation 2008 (ISG 2008)* titled 'Alternative UNBab Mapping Function After Simplification For GPS Tropospheric Delay' from 13 – 15 October 2008 at PWTC Kuala Lumpur.

Hamzah Sakidin , Mohd Rizam Abu Bakar, Mohd Rashid Md Shariff, Mohd Salmi Md Noorani, Abd. Nasir Matori. Simposium Kebangsaan Sains Matematik ke XV titled 'Simplification Of Tropospheric Delay Mapping Function For GPS Signal' on 5 - 7 Jun 2007 at Concorde Hotel, Shah Alam held by UiTM & PERSAMA. pp 55 - 62.

Hamzah Sakidin, 2008. Modeling and modification of GPS Tropospheric Delay Mapping Function, PhD thesis, University Putra Malaysia.

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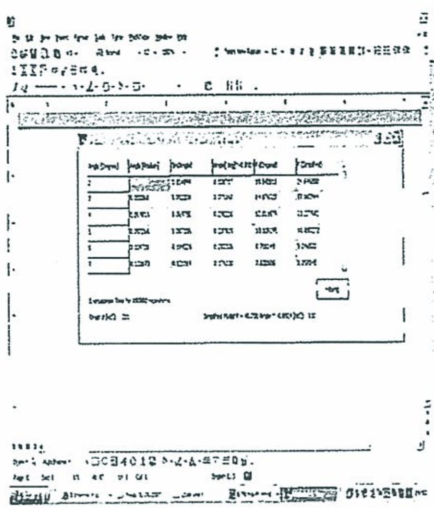
Appendix 1: Computation Time for *UNBab*



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MALAYSIA TECHNICAL UNIVERSITIES NETWORK

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

SIMPLER UNBab MAPPING FUNCTION FOR GLOBAL POSITIONING SYSTEM (GPS) TROPOSPHERIC DELAY

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ABSTRACT / INTRODUCTION

The $UNBab(E)$ mapping function models should be simplified to allow faster calculation and also better understanding of the models. Many modern mapping function models use mapping functions in the form of continued fractions which is quite tedious in calculation. There are 7 mathematical operations for $UNBab(E)$ to be carried out before getting the mapping function scale factor. The mapping functions for $UNBab(E)$ models for hydrostatic and non hydrostatic components are given in a form of continued fraction are to be simplified, due to its ability to calculate mapping function value down to 2 degree of elevation angle. By using linear, hyperbolic, logarithm and also regression method, the mapping function models can be simplified and at the same time can produce the same result. The calculation of sum of errors shows that the deviation of the simplified models from the original models is not significant. As a coefficient of zenith hydrostatic delay and also zenith non hydrostatic delay, the mapping function scale factor value plays an important role for getting the total tropospheric delay value.
So, this value will give minimum value for the tropospheric delay (TD) as given below (Schuler, 2001):

$$TD = ZHD.UNBab_h(\varepsilon) + ZWD.UNBab_{nh}(\varepsilon) \quad (1)$$

where: ZHD - zenith hydrostatic delay (m)
ZWD - zenith wet delay (m)
$UNBab_h(\varepsilon)$ - the hydrostatic mapping function (-)
$UNBab_{nh}(\varepsilon)$ - the non-hydrostatic mapping function (-)

SIMPLIFICATION PROCESS

The hydrostatic component of $UNBab(E)$ is written as:

$$UNBab_h(E) = \frac{1+\frac{a_h}{1+b_h}}{\sin E + \frac{a_h}{\sin E + b_h}} \quad (2)$$

where, E : elevation angle (radian)

The parameters a_h and b_h for the hydrostatic function are:

a_h =(1.53804-0.039491H+0.17020cos ϕ)/1000.

b_h =(50.0724-0.814759H+2.35232cos ϕ)/1000.

where H = 0.1km and ϕ is 45 degrees.

The mapping function for the original $UNBab_h(E)$, named as P shown in Figure 1.

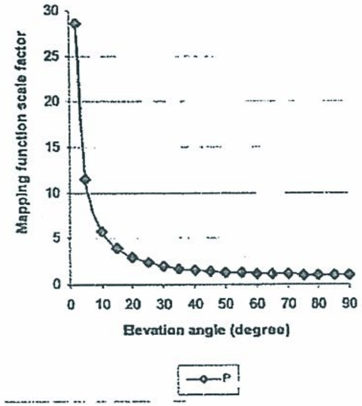

Figure 1: Graph of $UNBab_h$ mapping functions, P

Figure 1give a shape of hyperbola and equation (2) can be simplified as:

$$P1(E) = AE^B \quad (3)$$

where,
$P1(E)$:simplified $UNBab_h(E)$
A, B : constant
E : elevation angle (degree).

In logarithm scale, equation (3) can be written as:

$$\log_{10} P1 = B\log_{10} E + \log_{10} A \quad (4)$$

By linear regression method, equation (4) becomes:

$$\log_{10} P1 = -0.8924\log_{10} E + 1.6604 \quad (5)$$

where, B = -0.8924 and $\log_{10} A = 1.6604$ which gives $A = 45.751$.

Therefore, equation (5) becomes:

$$P1(E) = 45.751E^{-0.8924}. \quad (6)$$

By regression method, polynomial equation, log P2 can be generated from the original model (log P) in a form of quadratic equation as given below:

$$\log_{10} P2 = 0.1575(\log_{10} E)^2 - 1.2761(\log_{10} E) + 1.8509 \quad (7)$$

The graphs of P, P1 and P2 can be shown in Figure 2.

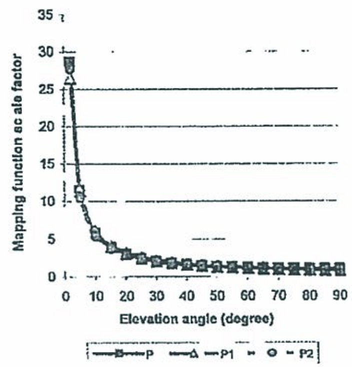

Figure 2: Graphs of P, P1 and P2 for $UNBab_h(E)$ mapping function

ADVANTAGES / CONTRIBUTIONS

Number of model operations

The simplified model only has 2 operations compared to the original model (7 operations), so the simpler model can reduce the number of operations up to 71.4% compared to the original model as shown in Table 1.

Table 1: Number of model operations

Model	Original model	Simplified model	Percentage of reduction
$UNBab_h$	7	2	71.4 %

Computation Time For $UNBab_h(E)$

The computation time for calculating (100,000 cycles) the original model and the simplified model for $UNBab_h(E)$ can be shown using CodeGear C++ Builder 2007 software (Table 2). The output for the computation times is shown in Appendix 1(Hamzah, 2008).

Table 2: Comparison for the computation time

Model	Computation time for original model (millisecond)	Computation time for simplified model (millisecond)	Reduction of computation time. (times)
$UNBab_h$	281	110	2.6

The computation time between the original model and simplified model shows that the simplified $UNBab(E)$ model is 2.6 times faster than the original model for hydrostatic component.

Calculation of Sum of Error For $UNBab_h(E)$

Sum of error (SOE) method can be used to show how the simplified models deviate from the original model. Smaller deviation is better, which shows that the simplified model is closer to the original model.

Table 3: Sum of error between P and simplified models P1

E	P	P1	ABS (P-P1)
2	28.628	24.646	3.982
5	11.470	10.880	0.590
10	5.758	5.861	0.103
15	3.863	4.082	0.218
20	2.924	3.157	0.234
25	2.366	2.587	0.221
30	2.000	2.199	0.199
35	1.743	1.916	0.173
40	1.556	1.701	0.145
45	1.414	1.531	0.117
50	1.305	1.394	0.088
55	1.221	1.280	0.059
60	1.155	1.185	0.030
65	1.103	1.103	0.000
70	1.064	1.032	0.032
75	1.035	0.971	0.065
80	1.015	0.916	0.099
85	1.004	0.868	0.136
90	1.000	0.825	0.175
TOTAL	71.625	68.135	4.87%

Table 3 shows the percentage of the sum of error is only 4.87% which shows that the simplified model is closer to the original model.

Therefore, the difference of tropospheric delay between the original model and the simplified model is not significance (less than 5% mapping function).

COMMERCIALIZATION

The simplified model can be used to replace the original model due to the smaller number of operations, smaller sum of error values and also the shorter computation time compared to the original model.
This study has a commercial value by replacing the continued fraction algorithm into either hyperbolic or linear form for its mapping function algorithm.

MALAYSIA TECHNOLOGY EXPO KUALA LUMPUR 2009 – Bronze Medal